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STRUCTURE AND EVOLUTION OF THE UNIVERSE SUBCOMMITTEE

OF THE
SPACE SCIENCE ADVISORY COMMITTEE

February 27–28, 2003

Jet Propulsion Laboratory
Pasadena, California

MEETING REPORT

Paul Hertz	**Edward W. Kolb**
Executive Secretary	**Chair**

STRUCTURE AND EVOLUTION OF THE UNIVERSE SUBCOMMITTEE (SEUS)
February 27–28, 2003
Jet Propulsion Laboratory
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MEETING MINUTES
TABLE OF CONTENTS

Meeting Report Prepared By:
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STRUCTURE AND EVOLUTION OF THE UNIVERSE SUBCOMMITTEE (SEUS)
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Thursday, February 27

Joint Meeting with Origins Subcommittee

Call to Order, Logistics, and Official Welcome
Dr. Edward "Rocky" Kolb, Chair of the Structure and Evolution of the Universe Subcommittee (SEUS), and Dr. Alan Dressler, Chair of the Astronomical Search for Origins Subcommittee (OS), opened the joint session of the two subcommittees. After brief introductions from those present, Dr. Tom Prince, Chief Scientist for Jet Propulsion Laboratory (JPL) welcomed the visitors to JPL and reviewed the important NASA activities in which JPL will be involved during the next year and a half. He noted the science payoffs that could be expected by 2004 from missions launched or in progress during fiscal year (FY) 2003. Dr. Paul Hertz, Executive Secretary for the SEUS, reviewed the rules for conduct of subcommittee meetings under the Federal Advisory Committee Act (FACA). SEUS and OS are technically subcommittees reporting to the Space Science Advisory Committee (SScAC), which is the advisory committee to NASA under FACA rules.

A&P Director's Report
Dr. Anne Kinney, Director of the Astronomy and Physics Division (A&P), of the NASA Office of Space Science (OSS), began her report with thanks to Dr. Dressler for his service as chair of OS and in developing the Origins roadmap. She introduced Dr. David Spergel, the incoming OS chair. Roadmaps have been completed for all the A&P themes and are being distributed. For the excellent OS and SEUS roadmaps, Dr. Kinney thanked the science members of the two subcommittees who gave their time, as well as the NASA Headquarters (HQ) staff leads. She stressed the value derived from the science community working together on the roadmaps. They have already had important impacts in increasing the OSS budget in the President's FY 2004 submission to Congress. Dr. Kinney noted the recognition in the media of the recent results from the Wilkinson Microwave Anisotropy Probe (WMAP), a Medium-class Explorer (MIDEX) mission that cost only $145 million and has already returned important evidence supporting the general model for post-Big-Bang inflation of the early universe.

Dr. Kinney's chief concerns in this year's program are the Space Infrared Telescope Facility (SIRTF), the final servicing flight to the Hubble Space Telescope (HST), the Gravity Probe B (GP-B) mission, securing and implementing the Beyond Einstein initiative (named after the Structure and Evolution of the Universe [SEU] roadmap developed by the SEUS), and replanning the James Webb Space Telescope (JWST). SIRTF is on schedule for an April 15 launch, although a delay in a Global Positioning Satellite (GPS) launch may interfere. To address HST servicing issues, she is setting up two review panels. One panel will consider the technical feasibility and cost of options for either attaching a propulsion module to move HST to higher orbit or allowing a controlled de-orbit at the end of its service life. The second panel will evaluate options for the final servicing mission to HST, currently scheduled for FY 2004, and planning for HST's remaining service life. Dr. Kinney currently favors a flexible return mission to bring Hubble back to Earth after it stops working, rather than a fixed cutoff in 2010. Additional effort to extend work by the Goddard Space Flight Center (GSFC) space telescope team on HST could detract from preparation for JWST. In response to a question, Dr. Kinney stressed that NASA is committed to keeping the funding for Hubble-related research and analysis (R&A) n place until JWST is operational. Even if HST ceases working or is brought down before then, NASA understands the value of continued R&A based on the rich archive of HST data.

NASA managers are losing confidence that GP-B, which is now on its fifth replan in 39 months and has an overrun of $169 million, will launch and operate successfully. Dr. Kinney is forming two review panels, the first of which will assess the technical readiness of GP-B for a successful launch. The second panel will review the GP-B science goals, given the long delay in launch, and assess their merit relative to other programs that may be hurt if GP-B were to receive the additional $36 million being requested. For

example, She wants to know how the science community views GP-B, compared with the Laser Interferometer Space Antenna (LISA). Dr. Kinney hopes to have both reviews completed in 45 days.

Beyond Einstein is now an approved program in the President's proposed budget for FY 2004 and the outyear budgets, but Congress has not yet dealt with it. Dr. Kinney thanked Dr. Sterl Phinney and the other members of the SEUS roadmap team for their hard work, which she believes helped significantly in justifying increases in the Code S budget and funding for LISA, Constellation-X (Con-X), and the Einstein Probes. A valuable aspect of the roadmap was the science community's consensus in setting priorities, rather than simply saying every possible project was equally important. Technical reviews are in progress now to assess the status of technologies for LISA and Con-X. OSS is working with the Office of Science and Technology Policy on multi-agency coordination. For example, there will be a joint response by NASA, the Department of Energy (DOE), and the National Science Foundation (NSF) to the National Academy of Sciences report, *From Quarks to the Cosmos*.

JWST is undergoing a replan, now that a contractor has been selected. Dr. Kinney's concern is that the cost estimate is now up to $1.6 billion, which is $300 million over budget, and an in-budget solution is necessary. Otherwise, important elements in the current JWST plan, such as the Mid-Infrared Instrument (MIRI), may be canceled as part of a mission descope, even though the European Space Agency (ESA) and member states have made commitments to JWST. On the positive side, ESA has committed to launch JWST, and there are now two potential suppliers for the focal plane arrays.

SAFIR Update

Dr. Dan Lester, University of Texas, gave the OS and SEUS a progress report from the study group for the Single Aperture Far Infrared Mission (SAFIR, pronounced "sapphire"). SAFIR will provide science capabilities called for in the OSS roadmaps and the *Decadal Survey* from the Space Studies Board of the National Research Council. There is no funding line for SAFIR yet in the NASA budget, but the SAFIR study group views it as a good addition to the mix of NASA science missions. SAFIR concept development will provide a path to future infrared (IR) astronomy missions. The broad arguments for SAFIR are presented in a working paper, *Community Plan for Far-Infrared/Submillimeter Space Astronomy*, which grew out of a workshop held in March 2002. Dr. Lester described the scientific value of SAFIR as a complement to JWST and the Atacama Large Millimeter Array (ALMA). He reviewed the activities of the study team since the workshop last March. SAFIR has been discussed at the SEUS meeting in May 2002, the SPIE conference in August, the COSPAR meeting in October, the Astronomy and Astrophysics Society (AAS) meeting in January 2003, and the New Millennium ST-9 workshop in February.

To date, SAFIR remains a set of science objectives, rather than a specific mission concept. Implementation options will derive from the science requirements and technology capabilities. Dr. Lester reviewed these science requirements in terms of five parameters: aperture, operating temperature, wavelength range, diffraction limit, and lifetime. The importance of SAFIR stems from the importance of the far-IR region for observing the universe. Half the luminosity of the universe is in the far-IR; it is particularly significant for investigating the young universe, star information, the youngest primordial gas clouds, and dust anywhere in the universe. Although results from the soon-to-be-launched SIRTF may well alter the key science drivers for SAFIR, Dr. Lester enumerated the current drivers as (1) resolution of the far-IR background, (2) understanding how primordial material forms stars from hydrogen gas, (3) understanding the role of active galactic nuclei (AGN) in galaxy formation, (4) bridging the gap between local high-mass star formation and starburst galaxies, (5) tracking pre-biotic molecules from cores to planets, and (6) identifying voids in debris disks around stars. SAFIR can be described as a chemistry probe of the warm cosmos because of its ability to resolve large molecules at high spatial resolution.

Possible SAFIR implementations range from a JWST-like telescope or a sparse aperture concept to a dual and amorphic reflecting telescope (DART). Technology needs common to all the implementation concepts include active surface control in deployment; large format, low-noise detectors; cryocoolers and thermal management; and large, lightweight optical structures. Dr Lester also described some critical technologies for which proof-of-concept incremental steps beyond current capabilities are desirable. He indicated ways that work on JWST, ST-9, and other work in Code R could help provide these technology extensions

needed for SAFIR. At far-IR wavelengths, point source sensitivity depends more on temperature than on aperture. The 4 K target operating temperature for SAFIRE would be background-limited in sensitivity. Dr. Lester presented the case for why the cryogenic technology needed to achieve this target is within reach, although beyond what is being done for the Planck and Astro-F missions. In summary, he described the SAFIR concept as a propitious convergence of science opportunity and technical feasibility. On behalf of the SAFIR study group, Dr. Lester asked OS and SEUS to (1) support technology development applicable to SAFIR, (2) support work with Code R for science-driven technology funding, (3) recommend continued funding for SAFIR concept development, and (4) acknowledge the *Community Plan for Far-Infrared/Submillimeter Space Astronomy* as an appropriate basis for a SAFIR funding line.

In response to the presentation, the two subcommittees discussed with the guests from OSS the current status of Code R cooperation in working out science-driven requirements for technology development. Progress is being made, but the subcommittees agreed on the importance of continuing to watch the process, to ensure that it works, not only for SAFIR-related technology but also for other technology needs identified in the OS and SEU roadmaps. The consensus was that the list of SAFIR near-term needs was consistent with the two roadmaps. In response to a question, Dr. Lester and Dr. Hashima Hasan noted that the March 2002 workshop from which the white paper developed was sponsored by NASA Headquarters and GSFC.

Presentation of the OSS Strategy

Dr. Philippe Crane of NASA Headquarters opened his presentation by noting that its aim is to prepare for OS and SEUS recommendations to the full SScAC, which will meet on March 3–5 at JPL. The document is now a first-draft plan, to which the SScAC can suggest revisions. However, the NASA Strategic Plan, which is already approved and released, drives the development of the OSS Strategy. The NASA Strategic Plan, which reflects a logical flow from the vision and mission statements down to objectives, has objectives tied to budget and performance metrics. The OSS Strategy links with the OSS objectives, along with their metrics, as defined in the NASA plan. This approach supports the President's Management Agenda (PMA) and the Government Performance and Results Act (GPRA). The NASA centers are working on implementation plans for the overall NASA strategy.

Project Prometheus is the new name for the nuclear power and propulsion efforts, much of which were previously under the Nuclear Systems Initiative (NSI). The OS and SEUS were asked to comment on the science theme sections for, respectively, Astronomical Search for Origins (§4.2.4) and Structure and Evolution of the Universe (§4.2.5) and on the corresponding Research Focus Areas in Appendix A-4. Also relevant to the two subcommittees are the Education and Public Outreach section (§4.1.4) and the technology requirements in Chapter 5. Theme-unique technology requirements are introduced in the theme sections of Chapter 4. The tables in the first two chapters and the NASA goals and objectives in Chapter 3 derive from the NASA Strategic Plan and are not open to revision. The Research Focus Areas are supposed to come out of the themes' roadmaps. Dr. Crane asked the subcommittees to prepare concise and reasoned recommendations to the SScAC on material in the draft that should be corrected or changed. The subcommittees' recommendations will be discussed in the open forum of the SScAC meeting, leading to advice from that committee to the OSS Associate Administrator.

SEUS-Only Session

After the presentation on the OSS Strategy draft, the joint session ended. The meeting adjourned briefly while the OS members left for their separate meeting. The SEUS chair then reopened the meeting.

SEU Theme and Beyond Einstein Update

Dr. Paul Hertz reviewed the status of the A&P operating and planned missions using stoplight charts to indicate status assessments. The High Energy Transient Explorer 2 (HETE-2) was yellow in January because a proportional counter window was punctured; the mission has been rebaselined to accommodate the loss. The Far Ultraviolet Spectroscopic Explorer (FUSE) was yellow in December because of a reaction wheel anomaly, which put FUSE in safe mode until the reaction wheel was restarted. Software to avoid the condition believed to cause the anomaly is being prepared. The Cosmic Hot Interstellar Plasma Spectrometer (CHIPS) mission was launched successfully on January 12, and science operations have started. The Galaxy Evolution Explorer (GALEX) is preparing for launch in March and is all green as well.

Gravity Probe-(GP-B) is on red status (feasibility in doubt). Work at GSFC on Swift lost a week to the snowstorm, but the team is proceeding now with integration. Astro-E2 is making technical progress with its mirrors and x-ray spectrometer, but Japan's Institute of Space and Astronautical Science (ISAS) is experiencing budget problems, which may delay Astro-E2 by 6 months. The Gamma-ray Large Area Space Telescope (GLAST) is progressing to Critical Design Review (CDR). The project is using some of its reserves to improve management. This large-area telescope is a multiparty effort with many international partners, and budget problems at foreign space agencies may affect 2003 obligations. Even so, Dr. Hertz believes the GLAST will be a high priority for the foreign partners. More problematic is work on the GLAST Burst Monitor (GBM), which the German Aerospace Center (DLR: Deutschen Zentrum für Luft- und Raumfahrt) may not start this year. NASA is working on bridging options but will be unable to make up the difference if DLR drops GBM completely. Detailed updates on the Herschel and Planck missions are later in the meeting agenda.

The Antarctic Long Duration Balloon (LDB) Program has had two successful flights in this year's campaign. The Advanced Thin Ionization Calorimeter (ATIC) flight ended after 20 days with payload recovery. The BOOMERANG flight lasted 15 days with partial payload recovery. The remainder of the payload is on the Antarctic ice sheet and will be recovered after the winter season. NASA and NSF have agreed on a plan for continuing the program. NASA is now responsible for the ballooning facility and, as its sole user, will fund a new building to support the program at McMurdo Station. NSF, as steward for all U.S. Antarctic science programs, will provide maintenance and support. NASA will buy the new generators needed for 2004; NSF will transport and install them. The 2004 campaign will occur, but the program will be suspended in 2005 while the new facility is built. A new memorandum of understanding (MOU) will formalize the new arrangements. Funding for NASA's increased responsibilities will come from the existing ballooning program, although the facility construction cost can be stretched over several years. Conventional ballooning in the Northern Hemisphere will be reduced to fund the new facility in Antarctica. The Russians did not sign the anticipated MOU allowing balloon overflights, so the two payloads planned for launch in June 2003 have been postponed. There is no plan yet for funding an ultralong duration balloon (ULDB) program. The current prototype flight is waiting on the pad in Alice Springs, Australia, for improved weather and wind conditions. An ULDB flight is included in the 2004 campaign.

For Beyond Einstein activities, the FY 2004 President's budget provides for launch of LISA in 2011 and a Constellation-X (Con-X) first launch in 2013, with a second in 2014. Funding for the Einstein Probes begins in FY 2007, but additional funding is needed to begin work on Probe technology before then. R&A funding for these missions is incorporated in the amounts shown in the President's budget. The President's budget emphasizes interagency coordination, and the Office of Science and Technology Policy is leading an Interagency Working Group on Physics of the Universe. NSF, DOE, and NASA are the key players, each having a cochair (Anne Kinney is the NASA cochair). The Department of Defense (DoD) and the Defense Advanced Research Projects Agency (DARPA) will be invited but are not expected to participate actively. One objective is to develop a coherent set of issues and recommendations that respond to the Turner Committee Report, *From Quarks to the Cosmos*. The participating agencies will respond with missions and other implementation activities. NASA aims to do the Einstein Probes as interagency efforts. A second objective for the Interagency Working Group is to resolve issues that limit collaboration across agencies. A NASA Research Announcement (NRA) has been released to solicit mission concept studies for the Einstein Probes, and NASA expects to select several concepts for each of three probes. Concepts can include involvement with other agencies (e.g., NSF), and NSF has said it will be responsive to proposals. The NRA also invites concepts for ways that NASA could work with DOE on the Supernova Acceleration Probe (SNAP), as well as other mission concepts for dark energy investigations. The SEUS discussed issues in collaborating with DOE, how to handle public access to data, avenues to increase funding for probe technology development, and protection of R&A funds to develop the science basis for OSS missions. Technology development for different probe types will aim at eventual mission Announcements of Opportunity (AOs). The missions will be fully competed, with NASA oversight of cost and schedule.

A technology readiness and implementation plan (TRIP) is in progress for LISA and Con-X. An independent evaluation team will review the key mission milestones and concepts, assess each mission's technology roadmap, assess feasibility of plans for phases A and B, and assess feasibility of the mission implementation plan. The latter assessment examines overall mission cost, schedule, and realism of

proposed launch dates. Evaluation teams will meet March 4–7 to discuss the plans for each mission. Con-X site visits are scheduled for March; LISA site visits are scheduled for April. The evaluation teams will report to Drs. Kinney and Weiler. After the TRIP review and incorporation of results, OSS will set up a Beyond Einstein Program Office, then start Einstein Probe mission concept studies. The Program Office will use these studies to define the science and technology needed to prepare for the missions. The SEUS discussed types of dark energy probes that might emerge from the NRA process, such as ways to study the cosmic microwave background (CMB).

Review of OSS Strategic Plan

The SEUS briefly discussed some of the wording in the first three chapters of the draft, with which members were dissatisfied. In particular, members noted that the omission of OSS from Goal 4 (Chapter 2 table) was inconsistent with the way the space science community views its role in exploring the "fundamental principles of physics, chemistry, and biology." However, the SEUS understood that the text in the first three chapters was not subject to change and moved on to consider members' comments on Chapters 4 and 5. Dr. Hertz noted that Congress, OMB, and NASA senior management will use the OSS Strategy as a baseline to grade OSS performance in achieving the OSS objectives. Most of the discussion of text focused on Section 4.2.5, "Structure and Evolution of the Universe." After revisions for specific paragraphs were discussed, the chair assigned one or more members to draft alternative text, to be suggested to the SScAC for inclusion in the next draft. The members also developed revisions for Section 4.1.2, "Scientific Research and Analysis," and Section 5.3, "Multi-Mission Technologies."

Planck Update

Dr. Charles Lawrence, NASA Planck Project Scientist, gave the SEUS an update briefing on the Planck mission. Planck is the third medium-sized mission in ESA's Horizon 2000 program. It is scheduled for launch in 2007 on an Ariane 5 rocket, together with the Herschel payload. Planck will be the third mission focused on observation of the CMB, after the Cosmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP). Planck's primary science goals are to measure the temperature anisotropy of the CMB to fundamental limits and to measure CMB polarization. Dr. Lawrence reviewed the science argument for Planck, which will measure an order of magnitude more multipoles for temperature anisotropy mapping than WMAP and will provide polarization maps, which WMAP does not. Data from Planck will have the sensitivity to differentiate among alternative theoretical models for reionization that cannot be differentiated with WMAP data. Differences in spectral degeneracies that are only marginally detectable with WMAP will be clearly detected by Planck. Planck will also produce the first all-sky surveys that are in the submillimeter wavelength region of the spectrum and detailed enough to map compact sources. As little is known about discrete sources in this wavelength region, the numbers of sources that could be detected can only be guessed. Compact sources located by Planck can be investigated in other frequencies using Herschel and ALMA. SEUS members discussed with Dr. Lawrence the importance of controlling systematic sources of error and foreground noise, if some of Planck's science objectives are to be realized. The frequency range coverage provided by Planck's two instruments is necessary to provide corrections for the many foreground noise sources.

With respect to the Planck spacecraft systems, the predecessor for Planck's cryogenic system is SIRTF, rather than the other CMB missions. The thermal system uses radiative cooling aggressively and has three stages of cryocooling. The third stage will cool the bolometers in the High Frequency Instrument (HFI) to 0.1 K. The bolometers have been proven on suborbital and balloon flights. The Low Frequency Instrument (LFI) uses a radiometer configuration, and the HFI sits inside the casing of the LFI. These two instruments will be the most sensitive ever built for their respective frequency ranges. The U.S. contributions to Planck are primarily in the detectors and cryocoolers. Redundant cooling systems will be present for both instruments. Dr. Lawrence reviewed results from recent instrument tests.

A significant change in Planck plans occurred last fall, when the Italian Space Agency (ASI) decided not to fund development of the 100 GHz channel on the LFI. NASA recognized the importance of having this channel and regretted the loss of science capability. Loss of this channel will reduce the LFI to being a support instrument, with mission success critically dependent on the functioning of the HFI and its coolers. The SEUS discussed with Dr. Lawrence the implications for increased program risk and decreased capability resulting from this change, as well as the possibility for recovering polarization detection

capability at 100 GHz by changing the planned spider web bolometers on the HFI to polarization-sensitive bolometers. The data analysis role for the U.S. team is equivalent in magnitude (about 20 to 25 percent) to the U.S. role in supplying system hardware. The single U.S. deliverable is an early-release catalogue of compact (bright) sources, scheduled for delivery 9 months from start of operations. (Further SEUS discussion of the Planck update occurred after the Herschel update.)

Herschel Update

Dr. Harold Yorke of JPL, the NASA Herschel Project Scientist and a SEUS member, provided an update on the Herschel Project. Herschel will launch on the same vehicle as Planck but the two payloads will fly in different orbits. Herschel is ESA's Cornerstone mission for far-infrared/submillimeter observing, similar in project scale to NASA's Great Observatory class. Its three instruments are the Heterodyne Instrument for the Far-Infrared (HIFI), Spectral and Photometric Imaging Receiver (SPIRE), and Photodetector Array Camera and Spectrometer (PACS). All three instruments use one 3.5-m telescope. NASA has significant roles in building HIFI and SPIRE. The spacecraft measures 9 m (axial) by 4.5 m (diameter) and has a 1 kW power requirement. Operating during the period 2007 to 2012, Herschel will be the only infrared/submillimeter observatory in space between SIRTF and JWST. It also partially fills the wavelength gap between ALMA and JWST. This far-infrared/submillimeter region is important for studying interstellar dust, specific atomic and molecular emissions, and bending-mode emissions of large molecules. HIFI will be able to resolve the spectral fine structure of elemental and molecular emissions from the interstellar medium and trace concentration contours in dense molecular clouds. HIFI's spectral line profiles, combined with existing line surveys, will allow three-dimensional reconstruction of complex regions in the Milky Way and nearby galaxies. Another use for Herschel will be sky surveys for high-redshift galaxies. It will map the large-scale structure of the high-redshift universe and provide star formation histories for galaxies at redshifts as high as 5.

Herschel's L2 orbit will allow 22 hours per day of observing time. In addition to the access to guaranteed time based on U.S. contributions to the instruments, Dr. Yorke expects U.S. investigators to do well in the peer-selected proposal process for general observers. NASA and the U.S. Herschel project team will be supporting the U.S. community in using the observatory through direct funding for data analysis and through operation of the NASA Herschel Science Center at the Infrared Processing and Analysis Center (IPAC). He reviewed the U.S. contribution to design and construction of HIFI and SPIRE (additional details for SPIRE photometer and spectrometer structure are in the briefing slides). In December 2002, the local oscillator multiplier chain for HIFI was successfully demonstrated. Dr. Yorke reviewed the schedule for additional tests and delivery of components and assemblies, leading up to the mid-2007 launch date. The NASA project scientist assessment for Herschel is that all U.S. components are on track. JPL expects to meet its commitment dates for all critical deliverables. There are some concerns with whether the European instrument teams and Alcatel, the prime contractor, can meet the ambitious schedules for their commitments.

SEUS members suggested that there would be considerable value—for this subcommittee and other audiences, including those who control funding and budgets—in a presentation that gave a broad conceptual map of how the various NASA and ESA missions, such as Herschel, Planck, SIRTF, and JWST, cover the spectral regions and astrophysical phenomena of interest to SEU and the other OSS themes. The mission-specific presentations typically mention some comparisons and potential for complementarity with one or more prior or concurrent missions. But a holistic view is needed of how the missions and their instruments cover the "scientific field" of interest—and where there may be gaps or areas of weak coverage. Another issue discussed was the risks and rewards of seeking and relying on foreign commitments to joint projects. SEUS members expressed concern that incidents such as the decision to drop the 100-GHz channel on the Planck LFI could undermine the capabilities missions require to meet their science goals. Another issue is that data accessibility for Herschel will be determined by European rules, rather than NASA practices.

RadioAstron Project

Dr. Edward Formalont of the National Radio Astronomy Observatory (NRAO) and Dr. Jeffrey Hayes from NASA Headquarters described the RadioAstron Project, with particular attention to the Russian request for expanded NASA participation and financial support. NASA is assessing whether and how it should

continue to support the mission and would like input from the SEUS on its scientific value. RadioAstron is an international mission with the Russian Space Agency as lead and many other agencies participating, including NASA. The original schedule was upset by the Russian financial crisis, and the replan calls for launch in March 2006. The 10-meter antenna on the spacecraft in earth orbit will be used with a very large baseline interferometry (VLBI) ground network to produce high-resolution images. RadioAstron's potential for unprecedented resolution stems from its high orbit, which is approximately 300,000 km at apogee (10 times higher than the VLBI Space Observatory Programme [VSOP] mission). The science goal is to obtain 1.5 microarcsecond resolution for compact objects such as AGN. However, the orbit is highly elliptical, and at perigee is similar in altitude (550 km) to VSOP's orbit. Because of severe perturbation by the Moon at the high end, the orbit will require constant modeling and recalculation to support the VLBI computations. Simultaneity of observations at the space antenna and ground antennas is critical to the science objectives, such as studying strong radio scintillators.

The value of RadioAstron depends on its launch being on time, so that its nominal three-year mission fits in the time gap between VSOP (launched by the Japanese in 1997) and future next-generation VLBI missions. NASA sees significant challenges in achieving a successful launch by 2006, and a launch after that decreases the mission's scientific value because other space VLBI missions of similar or better capability are being planned for launch after 2009. (These projects in planning include the Advanced Radio Interferometry between Space and Earth [ARISE], an international ARISE [iARISE], and VSOP2.) Most of the foreign partners delivered their promised RadioAstron equipment in the early 1990s. In some cases, the provider no longer certifies the flight survivability of the equipment because of its age. The program delays have led to resource reallocations at most of the foreign partners, including NASA, and they have no budget to continue supporting the mission, including refurbishing any of the already-delivered equipment. The only flight-ready receiver is a new 1.35 cm (22 GHz) receiver from NRAO. The Russian agencies involved have not yet reached agreement on whether the other stored foreign equipment can be used, as it does not meet their own flight specifications. The proposed NASA participation would be similar to NASA's participation in VSOP: provision of ground stations, orbital determination, access to a VLBI correlator, and data archiving. The Russians cannot perform the required orbital determinations without support from JPL. Another problem is that two VLBI ground stations from the United States have been requested, but only the Greenbank station could be easily reassembled. Providing a second station would be costly. NASA estimates the cost of the proposed participation, with only the Greenbank station instead of the requested two stations, at $12.3 million. This estimate assumes no cost-increases due to schedule slips. NASA would need to put at least $715 thousand into refurbishing Greenbank this year, just to keep on schedule for its proposed commitments. The funding for a RadioAstron commitment would come from other science missions, such as the newly programmed Einstein Probes. If it decides to participate, NASA would negotiate a new MOU with an exit clause if progress does not continue toward a launch on the proposed schedule.

Day 1 Discussion of Issues

The SEUS discussed whether support for RadioAstron was justified by the science advantages of the mission as now planned. The members discussed issues of antenna resolution versus sensitivity, the potential improvement over VSOP results (the 22-GHz receiver would be a valuable capability, as VSOP's 22-GHz receiver failed, apparently during launch), and the prospects for RadioAstron as a "pathfinder" to aid in refining mission parameters and planning for subsequent VLBI missions. They also discussed feasibility of the schedule, credibility of the mission planning, the extent of development, integration, and testing still to be done, and whether a second ground station would be essential. The consensus view was that the balance of science returns versus program risks was not favorable. Dr. James Ulvestad agreed to draft a SEUS statement for review and consideration on Friday.

Next the SEUS discussed recommendations Dr. Kolb should address to the full SScAC at its March 3–4 meeting. The A&P Director's approach to reviews for the replan of GP-B was discussed, and members were assigned to draft SEUS statements for review and consideration on Friday. After additional discussion of members' views, drafting assignments were made for SAFIR, Planck, and Herschel. The earlier assignments for recommended changes to the OSS Strategy were reviewed. The chair then adjourned the meeting until Friday.

Friday, February 28

Joint Session with Origins Subcommittee (OS)
The SEUS and OS met in a second joint session, which started at 8:30 a.m. on Friday, February 28.

OSS Budget Outlook
Dr. Edward Weiler, NASA Associate Administrator for Space Science, presented the Space Science Enterprise budget for FY 2004 as it appears in the President's budget proposal to Congress. The upward trend for OSS that started with the FY 1999 budget continues through FY 2008. Full-cost accounting is affecting NASA as a whole this year, but affects OSS less because JPL has been on full-cost accounting for 40 years. Dr. Weiler reviewed the increases in each OSS theme, with particular attention to the outyear growth for SEU as Beyond Einstein funding increases. With SEU receiving funding for Beyond Einstein this year, each OSS theme has now gotten a desired new initiative. The three new initiatives this year are (1) incorporation of the existing NSI program and the new Jupiter Icy Moons Orbiter (JIMO) into Project Prometheus; (2) an Optical Communications program, which will use adaptive optics for greatly increased data communications from Mars and outer-planet missions; and (3) development funding for three elements of the Beyond Einstein program—LISA, Con-X, and the Einstein Probes.

JIMO will be the first mission to use the new nuclear power and propulsion technologies from Project Prometheus (i.e., reactor-derived energy, rather than natural radioisotope decay, as in RPSs). A NRA for JIMO mission concepts exploiting these greatly increased energy and power levels will be released soon. Dr. Weiler noted that the plans for JIMO respond to the *Decadal Survey* recommendation that a mission to Europa be the flagship mission for exploring the outer solar system. He illustrated the value of nuclear power/propulsion technology for science missions through examples of the anticipated science return from JIMO, relative to previous or proposed missions relying on chemical (battery) or radioisotope-decay (RPS) energy sources. With respect to safety concerns, Dr. Weiler summarized NASA's 30 years' experience in successfully managing 17 RPS-powered missions, plans for cooperation with the DOE on design, manufacture, and flight of fission reactors, and NASA's intent to comply fully with approval processes applicable to the use of nuclear power systems in space.

Dr. Weiler gave examples of the improvements in data communication rates possible with advanced optical communications and the implications for increased science returns from existing and planned instrument technologies in the Mars Exploration Program and exploration of the outer planets. He also reviewed the capabilities and science objectives of the LISA, Con-X, and Einstein Probes projects in the Beyond Einstein initiative. Seven space science launches are scheduled for calendar year 2003, excluding GP-B, which is scheduled for September but under review. The OSS education and public outreach (E/PO) program has expanded significantly over the past 13 years. NASA's space science missions continue to rate highly in the *Science News* metrics for discoveries and technological achievements that gain public attention.

With respect to the science community's concerns about funding after HST ceases operations, Dr. Weiler asked Dr. Kinney to draft a letter to the editor of the *AAS Newsletter* stating that NASA funding for HST data analysis will continue for years. Dr. Weiler discussed with SEUS the missions that could sustain public interest in space science during the next several decades. With respect to the impact of the Columbia disaster on OSS missions, he said that a possible delay in the final mission to service HST is the only effect evident at present. Other discussion topics were the options for HST end-of-service and potential impacts on follow-on missions, such as JWST, if funds are diverted to sustain HST longer than planned. With respect to the GP-B reviews and proposed replan, Dr. Weiler said he will require a successful full thermal vacuum test before approving a launch. He supports the approach of asking the science review panel to weigh the value of GP-B against alternatives such as LISA, since it will be the other SEU programs that will be reduced if GP-B is refunded. Dr. Weiler is pleased that the NASA vision now reflects much of what OSS was putting in its strategic plans 5 years ago.

SEUS-Only Session
After the discussion with Dr. Weiler, the joint session adjourned and the SEUS and OS returned to separate sessions for the remainder of their formal meetings.

Day 2 Discussion of Issues

Dr. Kolb opened the discussion by reviewing the issues for the Suborbital Balloon Program presented at the December 2002 SEUS meeting. The members discussed these issues, including the ULDB test this year, its place in the continuation of the Antarctic Balloon Program, and the additional resources needed to develop payloads that are adequately engineered for the longer duration of ULDB flights. The position SEUS should take on the GP-B reviews and replan was discussed, and a consensus was reached. Other issues addressed were the implications for SEU science objectives of difficulties in interagency cooperation/coordination and the vagaries of participation by foreign national space agencies in space science missions. Potential dates for the next two SEUS meetings were also discussed.

Presentation of Issues to the A&P Director

During the SEUS discussion of issues with Dr. Anne Kinney, A&P Director, an individual SEUS member introduced each topic. This introduction was followed by open discussion between Dr. Kinney and SEUS members. The SEUS commended the SAFIR effort and said that the funds provided by NASA have been used effectively by the study group. The SEUS encourages this kind of seed activity to develop the science base for potential projects and will recommend to the SScAC that appropriate measures be taken to support the efforts in far infrared/submillimeter observing developed by the community and presented in the *Community Plan for Far-Infrared/Submillimeter Space Astronomy*. The SEUS applauds the move by Code R to pursue science-driven technology through closer coordination with Code S. Dr. Sterl Phinney added that SAFIR is a good example of SEU-related missions that have been recommended in the *Decadal Survey* and other venues and are worth attention from NASA, even though they were not given top priority in the *Beyond Einstein* roadmap.

With respect to the Planck mission, the SEUS expressed concern for the loss of the 100 GHz channel on the LFI and favors the option of providing polarization sensitivity for the HFI bolometers. Under the circumstances, having polarization sensitivity on the Planck HFI is significant for the science return from this mission. Dr. Kinney agreed with the concern and noted that the scientific rationale is clear; the difficulty is in finding additional funding, given competing concerns with other science missions. The SEUS remarked on the unique scientific potential of the Herschel mission and endorsed continued NASA participation in the Herschel project. However, the Subcommittee does have concerns about the schedule and requested a further update on Herschel's progress at its next meeting. With respect to the proposed RadioAstron participation by NASA, the sense of the SEUS was that this could potentially be a pathfinder mission useful for designing the next-generation VLBI projects. However, the project circumstances, particularly the substantial risks, make fulfillment of this role uncertain. The SEUS was concerned about the lack of financial and technical contingency reserves in the proposed approach and will recommend to the SScAC against expending NASA resources to support the mission.

The SEUS emphasized the benefits and cost-effectiveness of the suborbital balloon program. Particularly significant are the emerging ULDB potential and the program's value for involving students in space science. Because the payload cost for ULDB missions will be beyond the range of the shorter duration missions of the past, NASA will need a mechanism to provide sufficient funding for payload development. Dr. Kinney and SEUS members discussed the implications of the recent NASA-NSF agreement on support for the Antarctic Balloon Program, which increases the portion of the program's cost borne by NASA. SEUS members noted that ULDB is a new capability and new responsibility for NASA. It may require rethinking about the long-term direction and scope of NASA's suborbital balloon program. The SEUS will endorse to the SScAC the NASA plan for review panels on the technical and scientific status of GP-B. A major concern is that the cost of the new replan will be large enough to cut into other SEU projects. The SEUS will emphasize to the SScAC that the science panel in particular should be constituted to provide broad input from the SEU science community on the value of GP-B relative to other missions, such as LISA, Con-X and the Einstein Probes, which could be affected if GP-B is refunded.

SEU Projects at JPL

Dr. Charles Beichman, Chief Scientist for Astronomy and Physics at JPL, introduced the presentations on SEU work underway at JPL. This work is addressing the science of issues in CMB, dark energy, the formation of stars and galaxies in the early universe, black holes, and gravitational wave astrophysics. The

primary areas of technology R&D include observing at long wavelengths in the electromagnetic spectrum (e.g., bolometers, amplifiers, cooling technology, and apertures). Dr. Beichman noted the individual JPL staff members working on the various projects in these science and technology areas.

Dr. Tom Prince spoke to the SEUS as the NASA mission scientist for LISA science and technology at JPL. He provided a topical update on current activities for LISA, which will involve three spacecraft flying in a triangular configuration, with the relative distances between their detector masses measured by heterodyne interferometry. The mission will investigate features such as massive black holes, the inspiral of stellar-mass compact objects, and other phenomena producing gravitational wave characteristics. The JPL team delivered the LISA TRIP report, and the TRIP panel will be visiting the site on April 1. A division of responsibilities between ESA and NASA has been worked out. Dr. Prince described the LISA science team, extensive E/PO activities in progress, and LISA flight technology verifications that are underway. The LISA International Science Team (LIST) is an advisory group, under which are small permanent working groups. The working groups draw on the expertise of many individuals through ad hoc task groups for topics such as extreme mass ratio inspirals, phase locking and stabilization, and source subtraction algorithms. At least a dozen U.S. universities are represented in LIST, which has been conducting meetings and other activities since December 2001. Dr. Prince noted the importance of early R&A work for developing the theory underpinning LISA objectives and overcoming the computational challenges. Important technology verifications are underway on three components of LISA technology: picometer interferometry, micro-newton thrusters, and the Disturbance Reduction System (DRS).

Dr. William Folkner described the ST-7 technology verification effort, which will fly on the second of ESA's Small Missions for Advanced Research in Technology (SMART-2). SMART-2 is scheduled to launch in 2006. The ST-7 objective is to validate the capability for a test mass to follow a purely gravitational trajectory. A picometer interferometer will be used to measure the distance between two test masses, and several new types of low-force thrusters will be tested for maintaining the position of the spacecraft relative to the test masses. Dr. Folkner explained the technology development pathway from the SMART-2 technology to technology goals for the DRS and LTP payloads on LISA. He presented the near-term schedule for SMART-2 key events.

Dr. Jamie Bock described technology development at JPL for CMBPOL, which has been proposed as a Beyond Einstein mission to look for the CMB signature of post-Big Bang inflation. The instrumentation would have 20 to 100 times the sensitivity of Planck by using large focal plane arrays of millimeter-wave bolometers The target sensitivity is 2 μK per pixel. Comparison of results from the MAP mission and the 2003 BOOMERANG balloon flight show that bolometers can give good reproducibility in measuring CMB polarization. A major technology challenge will be collimating millimeter-length gravity waves on such an array. A technology alternative to the focal plane array would use antenna-coupled bolometers.

Dr. Kolb adjourned the formal meeting of the SEUS at 11:45 a.m.

Tour of JPL

After the formal adjournment of the SEUS meeting, members of SEUS and OS toured the JPL laboratories directly engaged in work for, or relevant to, SEU and OS projects.

AGENDA

Structure and Evolution of the Universe Subcommittee (SEUS)

February 27–28 2003
Jet Propulsion Laboratory

Thursday February 27

Joint Session: Building 167 Conference Room

8:00	10 min	R. Kolb, A. Dressler	Call to order
8:05	5 min	M. Devirian	Logistics
8:10	5 min	T. Prince	Official Welcome
8:15	45 min	A. Kinney	A&P Director's Report
9:00	30+15 min	D. Lester	SAFIR Update
9:45	20 min	P. Crane	Presentation of OSS Strategy
10:05	15 min	Break and go to split sessions	

SEUS Only: Building 167 Conference Room

10:20	30+30 min	P. Hertz	SEU Theme and Beyond Einstein Update
11:20	40 min	All	Review of OSS Strategy
12:00	60 min	Working Lunch: Continued Review of OSS Strategy	
1:00	30+15 min	C. Lawrence	Planck Update
1:45	30+15 min	H. Yorke	Herschel Update
2:30	15 min	Break	
2:45	30+30 min	E. Fomalont, J. Hayes	RadioAstron Project
3:45	105 min	R. Kolb et al.	Discussion of issues
5:30		Recess for day	
TBD		SEUS Committee Dinner	

Friday February 28

Joint Session: Building 167 Conference Room

8:00	60 min	E. Weiler	OSS Budget Outlook
9:00	15 min	Break and return to split sessions	

SEUS Only: Building 167 Conference Room

9:15	45 min	R. Kolb et al.	Discussion of issues
10:00	60 min	R. Kolb et al.	Presentation of Issues to A&P Director
11:00	60 min	TBD	SEU Projects at JPL
12:00	Adjourn		
12:00	60 min	Lunch break	

By invitation only:

1:00	120 min	Tour of JPL	

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Note: Expiration Dates in Bold

Updated 2/25/03

STRUCTURE AND EVOLUTION OF THE UNIVERSE SUBCOMMITTEE (SEUS)
February 27–28 2003
Jet Propulsion Laboratory
Pasadena, California

MEETING ATTENDEES

Subcommittee Members:

Kolb, Edward "Rocky" *(Chair)*	Fermi National Accelerator Laboratory
Cherry, Michael	Louisiana State University
Cominsky, Lynn	Sonoma State University
Dermer, Charles	Naval Research Laboratory
Finn, Lee Samuel	Pennsylvania State University
Flanagan, Kathryn	Massachusetts Institute of Technology
Hertz, Paul *(Executive Secretary)*	NASA Headquarters
Hewitt, Jacqueline	Massachusetts Institute of Technology
Hogan, Craig	University of Washington
Peterson, Brad	Ohio State University
Phinney, E. Sterl	California Institute of Technology
Swordy, Simon	University of Chicago
Ulvestad, James	National Radio Astronomy Observatory
Wright, Edward	University of California, Los Angeles
Yorke, Harold	NASA/JPL

NASA Attendees:

Ahmed, Mansoor	NASA Headquarters
Benford, Dominic	NASA/GSFC
Beichman, Charles	NASA/JPL
Breckinridge, James	NASA/JPL
Devirion, Mike	NASA/JPL
Dooley, Jennifer	NASA/JPL
Dragovan, Mark	NASA/JPL
Flemijes, Robert	NASA/JPL
Fujita, Tosh	NASA/JPL
Hasan, Hashima	NASA Headquarters (OS Executive Secretary)
Hayes, Jeffrey	NASA Headquarters
Kinney, Anne	NASA Headquarters
Lawson, Peter	NASA/JPL
Ling, James	NASA/JPL
Levin, B. Martin	NASA/JPL
Leisawitz, Dave	NASA/GSFC
Minning, Chuck	NASA/JPL
Nelson, Robert M.	NASA/JPL
Oegerle, William	NASA/GSFC (OS member)
Pilcher, Carl	NASA Headquarters
Prince, Thomas	NASA/JPL
Sarohia, Virendra	NASA/JPL
Ustinov, Eugene	NASA/JPL
van Zyl, Jakob	NASA/JPL
Weiler, Edward	NASA Headquarters
White, Nick	NASA Headquarters
Wilcox, Jaroslava	NASA/JPL

Other Attendees:

Arenberg, Jonathan	NGST
Bauer, David	NGST
Beckwith, Steven	STSCI
Blaes, Omer	University of California, Santa Barbara (OS member)
Bradford, Matt	California Institute of Technology
Burrows, Adam	University of Arizona (OS member)
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Formalont, Edward	National Radio Astronomy Observatory
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Saha, Abbijit	National Optical Astronomy Observatories (OS member)
Spergel, David	Princeton University
Terierelli, Dominick	LMSSI

STRUCTURE AND EVOLUTION OF THE UNIVERSE SUBCOMMITTEE (SEUS)
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LIST OF PRESENTATION MATERIAL[1]

1) Briefing slide package: *SAFIR: The Single Aperture Far Infrared Mission*. Dr. Dan Lester.
2) *Community Plan for Far-Infrared/Submillimeter Space Astronomy*, February 21, 2003
3) NASA Strategic Plan 2002 [check title]
4) *2003 Space Science Enterprise Strategy, Draft 2, February 6, 2003*
5) Briefing slide package: *Space Science Strategy: Presented to the Origins and to the SEU Advisory Subcommittees, February 2003*.
6) Briefing slide package: *SEU Theme Update*. Dr. Paul Hertz.
7) Briefing slide package:*Planck*. Dr. C. R. Lawrence.
8) Briefing slide package: *NASA Herschel Project: A Status Report on the Herschel Project presented to the Structure and Evoluton of the Universe Subcommittee*. Dr. Harold W. Yorke.
9) Briefing slide package: *Possible NASA Participation in RadioAstron*. Edward Formalont, Chris Savinell, and Jeffrey Hayes.
10) Briefing slide package: *Space Science Enterprise: Presentation to the SEUS/OS*. Dr. Edward J. Weiler.

[1] Presentation and other materials distributed at the meeting are on file at NASA Headquarters, Code S, Washington, DC 20546.